Thermal-Hydraulic Research Program at NRC

Dr. Jennifer Uhle
Director, Division of Systems Analysis
Office of Nuclear Regulatory Research
USNRC
Contents

• NRC program goals
• Use of tools at NRC
• Status of code development efforts
• Future code development efforts
• Rod Bundle Heat Transfer Program
• Interfacial Area Transport Program
• Summary
NRC Program Goals

• RES mission
  – Provides NRC with technical advice and tools for identifying and resolving safety issues
  – Conducts independent experiments and analyses to support regulatory findings
  – Prepares the agency for the future by evaluating safety issues involving current and new technologies

• Thermal-Hydraulics program
  – This mission is accomplished, in part, by maintaining, developing and using TRACE
  – TRACE must be accurate, applicable to all NRC reviewed designs and easy to use and easy to maintain and develop
    • In-house development team
Use of TRACE at NRC

• TRACE is used by RES and the regulatory offices to:
  – Review licensee submittals (power uprates)
  – Review vendor designs
  – Review licensee T-H methods
  – Generate success criteria for NRC’s PRAs
  – Investigate safety questions
    • sump clogging
    • CRDM and LHP breaks
  – Support rulemaking
    • Redefinition of large-break LOCA size
    • Fuel rod embrittlement criteria (boundary conditions)
Brief History of TRACE

• NRC consolidated the capabilities of TRAC-P, TRAC-B, RELAP, and RAMONA into a single computational platform
• Consolidation included modernization to make the code more extendible and easy to develop (TRAC-M)
• Initial assessment (500+ tests) performed identified some deficiencies
  – Conceptual problems
  – Separate effects tests
  – Integral effects tests
• Model improvement & error corrections made
  – Robustness
• Peer Review
• Assessment continues (matrix grows)
• Model development on-going
• Extension of assessment to new designs
• Input deck development for operating and new plants
  – ESBWR, EPR, US-APWR, 8 plant and containment types
  – TRAC-P, TRAC-B and RELAP5 input decks can be read by TRACE via SNAP
SNAP Input Preparation
Component Data Model

• All Component Data is Declared Private
• Views Implement a ComponentListener Interface
• Changes to Component Data are Automatically Reflected in all Views.
SNAP Output Visualization
TRACE Development / Assessment

Identify Plant & Scenario

PIRT (Phenomena Identification & Ranking Tables)

Establish Assessment Matrix

Experimental Testing & Data Evaluation

Model Development

TRACE Model Acceptable?

Yes

Deficiency

Code Assessment
Compare Code vs. IET and SET

Application

Uncertainty Methods
T/H Assessment Tests

Separate Effects Tests: Phenomena

- ANL Nat. Circ. Loop
- Dehbi Condensation
- CISE Adiabatic Tube
- FRIGG; 36 rods
- RBHT; 45 rods
- THETIS; 64 rods
- THTF; 64 rods
- FLECHT; 98 rods
- FLECHT Skewed; 108 rods
- G-2 Bundle; 336 rods
- MB-2 SG Tests
- Mariken
- UPTF: 1:1

Small Scale

- LWR 1:1
- Full Scale

Integral Effects Tests: System Interactions

- LWR 1:1
U-Tube Manometer Problem

Known or well accepted solutions

Relatively simple models

\[ X(t) = 4.5 + \frac{2.1}{\sqrt{L}} \sin\left(\frac{2\pi t}{L}\right) + 0.002\cos\left(\frac{2\pi t}{L}\right) \]
TRACE V5RC1 Results
FLECHT-SEASET Test 31805

Cladding Temperatures
Heat Transfer Coefficients
Bundle ΔP
• Upon completion of documentation, we sponsored a peer review of TRACE
  – Provided critical review of conservation equations & numerical solution methods as applied, models and correlations, and special features within TRACE
  – Commented on the assessment matrix; breadth & range of conditions
  – Commented on the documentation; clarity, ease-of-use, thoroughness

• Peer review panel consisted of 4 experts in the field of thermal-hydraulic code development
  – Confirmed our development plans
  – Need to improve documentation
Future Development

• Upcoming development efforts intended to address deficiencies:
  – Droplet field & entrainment modeling
  – Spacer grid models
  – Interfacial drag model improvements

• Development of an uncertainty methodology
  – Using TRACE to range parameters
  – NRC/industry workshops on standard

• Advanced LWR design support
Rod Bundle Heat Transfer (RBHT)

• The RBHT Program is being conducted at Penn State Univ. to provide high quality experimental data for:
  – Reflood Thermal-Hydraulics
  – Steam Cooling Convective Heat Transfer
  – Two-Phase Void Distribution (Interfacial Drag)
  – Dispersed Droplet Film Boiling

• Each test series has provided information on spacer grid effects. Grid is a MVG similar to that in W 17x17 V5H fuel assembly.)
RBHT – Photo of Bundle and Instrumentation

Flow Housing Instrumentation
RBHT Findings

- Spacer grids can have a significant effect on rod bundle heat transfer due to
  - convective enhancement
  - grid rewet
  - entrained droplet break-up

- Video depicting phenomena

- TRACE can account for hydraulic losses due to spacer grids, but contains no models for convective enhancement, grid rewet, or droplet breakup
  - Assessment focused on these effects
Model Interactions in TRACE

TRACE Vapor Energy Equation

TRACE Entrained Field Equation

Droplet De-Entrainment & Re-Entrainment

Vapor Source Term ($\Gamma$)

Radiation Heat Transfer from Grid to Vapor

Spacer Grid Models

Radiation Heat Transfer from Grid to Entrained Droplets

Radiation Heat Transfer between Grid and Fuel Rod

Enhanced Single Phase Convective Heat Transfer

Spacer Grid Losses

 TRACE Momentum Equations

Fuel Rod Structure Equation
Assessment Findings

- TRACE achieves correct energy balance, but misses the local convective enhancement effect of spacer grids
- Predicted HTC is typical of fully developed flow
- Lack of droplet breakup at spacer grids contributes to poor cooling at high elevations in tests where dispersed droplet flow is expected
Figure B.7-74. Vapor Temperatures at 10 ft from Heated Bottom for Test 31203
Figure C.2-38. Rod Clad Temperature Comparison at 3.05 Meters above the Bottom of the Heated Rods in the High Powered Region - Run 62.
TRACE Model Development

• Activate third field to serve as “entrained droplet field”
  – Entrainment
  – De-entrainment

• Spacer Grid T/H Models being incorporated:
  – Continuous Phase Convective Enhancement
  – Spacer Grid Pressure Loss Coefficients
  – Entrained Droplet Breakup
  – Spacer Grid Rewet
Limitations of Flow Regime Models

• Use flow regime maps to determine the value of interfacial area concentration
  – Flow regime maps were developed with data under fully-developed, steady-state conditions
    • Do not dynamically represent the changes in interfacial structure
  – Flow regime maps were typically developed from tube data
    • Not prototypic of more complex geometries, such as rod bundles or reactor piping systems
  – Instantaneous changes in flow regimes can lead to non-physical oscillations and can limit accuracy
Static Flow Regime Maps May Not Generate Conservative Results

Example: ADS Discharge Line

Main Steam Line
- \( D = 1.0 \text{ m} \)
- \( V_b \approx 0.2 \text{ m/s} \)
- \( V_l = 1.2 \text{ m/s} \)
- \( t_d = 5.0 \text{ s} \)

\[ x \approx 2 \frac{L}{D} < l_d \]
Still bubbly

\[ x \approx 6 \frac{L}{D} \]
Stratified

A code using flow regime maps will predict stratified flow at the ADS Valve
NRC Sponsored IATE Research

• Experiments at the Thermal-Hydraulics Institute at Purdue University
  – Large Hydraulic Diameter Pipe Experiments
    • 6-in. (0.152 m) and 8-in. (0.203 m) vertical pipes
    • Exit pressures of 180 kPa and 280 kPa
    • Void fraction up to 80 percent
    • Mass flux up to 1000 kg/m²s
  – Rod Bundle Experiments
    • 8x8 full size BWR rod bundle test section
      – Acrylic test section for atmospheric tests
      – Stainless steel test section for high pressure tests
    • Void fraction and grid loss database
  – Heated Annulus Experiments
    • 1.9 cm OD heater rod inside a 3.8 cm ID Pyrex or stainless steel tube
    • Pressures up to 10 bar
Prior IAT Research

• Adiabatic Experiments Near 1 bar
  – ½”, 2”, 4”, 6” ID Tube Data

• Adiabatic High Pressure Experiments
  – Annulus 1½” OD, ¾” ID (< 10 bar)

• 2” Adiabatic Horizontal Flow Data
Need for Additional IAT Data

• Data for Interfacial Area Change at Changes in Geometry
  – Contraction & Expansion
  – Elbow
  – Tank to Pipe with Direction Change
  – Pipe to Tank with Direction Change
  – Tee Junction
• Nucleation Effect
• Condensation Effect
• Rod Bundle
• Effect of Fluid Properties
Summary

• RES development of TRACE is aimed at providing a tool for resolution of safety issues and for independent assessment of licensee and vendor submittals.

• Development is focused on resolving deficiencies in order of importance using PIRT insights:
  – Grid spacer model
  – Loop seal clearing

• International collaboration (CAMP, bilateral agreements) contributes to this development.